Chapter 6
Placement

Shotcreting can be a hazardous operation, especially if the work must be conducted in a relatively confined area. The critical hazards include control of the material (shooting), rebound, plugged nozzle, hose or coupling breaks, caustic materials, and dusting. All shotcrete operations must be performed in accordance with EM 385-1-1.

6-1. Preparations

a. Unformed sections.

(1) Earth surfaces. Where shotcrete is to be placed against earth surfaces, as in canal linings, the surfaces should first be thoroughly compacted and trimmed to line and grade. Shotcrete should not be placed on any surface which is frozen, spongy, or where there is free water. The surface should be kept damp for several hours before shotcrete is placed.

(2) Rock surfaces. Where shotcrete is to be placed against rock, all loose material, debris, dirt, or other foreign matter must be removed to allow good bond between the rock and the shotcrete. This may not be possible or advisable in hazardous underground applications.

(3) Concrete and masonry surfaces. Where shotcrete is to be used for repairing deteriorated concrete, it is essential that all unsound material first be removed. Chipping should continue until there are no offsets in the cavity which would cause an abrupt change in the thickness of the repair. The perimeter of the repair area may be sawcut or chipped with a slight taper to the center of the area. Feather edging should be avoided. After it has been determined that the surface (whether concrete, masonry, or steel) to which shotcrete is to be bonded is sound, it should be prepared by dry sandblasting, wet sandblasting, grinding, or high-pressure water jetting. Just prior to receiving shotcrete, all such surfaces should be thoroughly cleaned. Porous surfaces should be kept damp, but not wet, before placing shotcrete.

b. Formed surfaces. Forms should be made of plywood sheathing, expanded metal lath, or other suitable material, true to line and dimension. They should be adequately braced to ensure against excessive vibration and constructed to permit the escape of rebound and air during the gunning operation, particularly in the case of thick structural members. Columns should be formed only on two adjacent sides wherever possible. Satisfactory results may be obtained where three sides are formed, provided the width is at least 1.5 times the depth. Pilasters may be formed on two adjacent or opposite sides. The soffit and one side of beams should be formed, and shores should be set below the soffit in such a manner that no deflection will occur under the load to be imposed. Short, removable bulkheads may be used at intersections. The forms should be oiled or dampened and should be clean just prior to gunning.

c. Work area access. Safe, adequate scaffolding should be provided so that the nozzleman can hold the nozzle at the optimum angle and distance from the surface for all parts of the work. The scaffolding should also provide easy access to the shotcrete surface for screeding and finishing operations.

d. Reinforcing steel repair.

(1) Concrete around the reinforcing should be removed until clean, uncorroded steel is reached. Concrete behind reinforcing steel should be removed to a depth to allow proper placement from a nozzle angles not more than 45 degrees to the surface. This depth is often more than 1.5 times the bar diameter but not less than 1 inch. Reinforcing that is corroded so badly that its usable cross section is reduced must be replaced.

(2) Defective bars are removed by cutting out the defective length and replacing with a new section of reinforcing bar. New bars must be lapped appropriately. Alternate attaching schemes such as butt welding, mechanical splices and other means should be considered carefully.

(3) Anchoring new bars in the existing, sound concrete is done by drilling holes and anchoring the ends with an epoxy grout. The anchorage must be designed to fully develop the load capacity of the bar and accommodate edge conditions near the bar.

(4) Stirrups should be treated the same as bars. The design and placement of the steel should be accomplished to minimize interference with the shotcrete placement. All anchors and bars should be arranged in the repair so that proper cover with shotcrete is provided.

e. New reinforcement.

(1) Reinforcing in shotcrete is designed like conventional concrete. Wire fabric may be used in nonstructural or light structural applications to control the development and depth of shrinkage and temperature cracking.

(2) Wire fabric can control debonding or delamination of the shotcrete if either condition may exist. Small bar reinforcement may be added to fabric to resist movement of the fabric during shotcreting, and to reduce the number of required fabric layers. Bar reinforcement is seldom used in sections thinner than 1-1/2 inches. Wire fabric may be used in sections as thin as 3/4 inch. Steel fibers may be used in lieu of wire fabric. Wire spacing should be a minimum of 2 inches on center. Fabric should be tied similarly to bar reinforcement for shotcrete. Fabric sheets should be lapped one and one-half spaces in all directions. When several layers of wire fabric are required, the first layer is covered with shotcrete prior to placing the next layer, with ties extending from the first layer to the next. At least one layer of fabric is used for each 3 inches of shotcrete.

(3) Bar reinforcement must be sized and positioned to minimize interference with shotcreting. Generally, bar sizes smaller than No. 5 should be used. Larger sizes may be used, but great care must be taken when encasing them with shotcrete. If possible, lapped bars should be separated by at least three bar diameters. One layer of reinforcement is generally sufficient for sections 8 inches or less in thickness. Thicker sections require several layers of bars, with the outer layer spaced to allow easy access to the inner layers. Bars should be rigidly tied with 16-gauge wire to prevent vibration of the bars that could cause sagging of the shotcrete or poor bond. Tie wires should be bent flat in the plane of the mesh. Large knots of wire might become voids in shotcrete. Anchors to support reinforcement are spaced each way at a maximum of 36 inches for floor applications, 24 inches for vertical and inclined applications, and 18 inches for overhead applications. Horizontal reinforcement should not be placed less than 12 inches from the ground or floor slab, especially if loose soil or sand forms the horizontal surface. At this height, it is difficult to shoot from the underside of the reinforcement. There is also a strong tendency for the material stream to pick up sand, soil, or rebound from the ground, thereby creating severe sand pockets.

f. Anchorage. Anchorage of shotcrete follows practice for conventional concrete.

g. Alignment control. A variety of alignment control devices are required to establish the limits of shotcrete placement, including ground wires, guide strips, depth gauges, depth probes, or forms. Ground wires are usually 18 or 20-gauge, high-strength steel wires attached to a turnbuckle or spring to provide tension. Wires may be used to establish corners of the shotcrete work, and may be spaced at 2- to 3-foot intervals for screed guides for flat areas. Guide strips are wood lath attached to crosspieces at 2- to 3-foot intervals, used similarly to wires. Depth gauges, small metal or plastic devices attached to the surface to which shotcrete is being applied, indicate the resulting thickness of the shotcrete. They may be left in place, and slightly covered, if their presence is not damaging. Depth probes are stiff steel wire rods premarked with the thickness of shotcrete, which are inserted into the shotcrete to check thickness.

6-2. Batching and Mixing

a. Equipment. Batching and mixing equipment must be capable of maintaining an adequate and continuous flow of uniform material. Aggregate particles should be well coated with cement paste. Batching by mass is preferred and should normally be required. Water may be batched by mass or volume. For small jobs, approval may be given to batching by a volumetric container, provided periodic checks of mass are made, or batching by volumetric mobile-mixing equipment.

b. Jobsite mixing. Since many shotcrete jobs have a low production rate and are in isolated locations, mixing is often done by a small drum mixer at the jobsite. In such cases, the mixing time should not be less than 1 minute. Where other mixers are proposed, satisfactory evidence should be presented to show they are capable of thorough mixing. The mixer should be capable of discharging all batched material without any carry-over from one match to the next. It should be inspected and cleaned thoroughly at least twice a day, more often if necessary, to prevent accumulations of batched material and minimize unplanned shutdowns.

c. Dry-mix process.

(1) The moisture content of the fine aggregate should be such that the aggregate-cement mixture will flow through the delivery hose at a uniform rate. It

should not be wet enough to cause slugs in the line, but damp enough for good adhesion between the cement and aggregate and to prevent a buildup of electrostatic charges. The optimum moisture content will depend upon the delivery equipment being used, but it is generally within the range of 3 to 6 percent, by dry mass, for the fine aggregate fraction. The aggregate should be dampened or dried as required to bring the moisture to a satisfactory level. Fluctuations in moisture content should be avoided. The nozzleman must control the mixing water so that the surface of the shotcrete has a slight gloss. Too much water can cause sagging, sloughing, puddling, or drop out, especially in overhead work. Insufficient water is indicated by a dry, dark, sandy surface appearance. This condition increases rebound, creates sand pockets, makes finishing difficult, and can result in weak, laminated shotcrete.

(2) The preferred method of dry-mix batching for large shotcrete projects is to batch materials onsite on a concurrent continuous basis. This is best done using prebagged materials and premoisturizing equipment. However, for smaller projects it is common to batch aggregates, cement, and special materials at a conventional concrete batch plant and to mix in a transit mixer. This damp material is discharged from the transit mixer into the shotcrete gun. It is critical that the total elapsed time from batching to shooting not exceed 45 minutes during hot weather and not more than 90 minutes during cool weather. For low production rate operations these time limits result in batching only small volumes of dry-mix material, often 1 to 3 cubic yards.

(3) Where the cement-aggregate mixture is furnished to the dry-mix shotcrete equipment by truck mixer in the dry state already proportioned, CRD-C 31 (ASTM C 94) applies. Where the ingredients are delivered in dry form and proportioned and mixed at the site, conventional batching plant operations conforming to CRD-C 31 (ASTM C 94) or volumetric batching and mixing plant operations conforming to CRD-C 98 (ASTM C 685) should be used.

(4) For mixtures containing silica fume, prebagging of all materials should be strongly considered. Shotcrete, exceeding the time limits stated in paragraph 6-2, will tend to form balls of cement and silica fume as the mixture continues to roll in the mixer drum. The shotcrete product will exhibit higher rebound, lower strengths, and lower cohesion and adhesion.

d. Wet-mix process.

(1) Batching and mixing operations should generally follow the guidelines given in ACI 304. Where ready-mixed concrete is used, it should conform to CRD-C 31 (ASTM C 94). Some pneumatic-feed guns have two chambers to permit continuous gunning. Concrete is mixed in one chamber while it is being withdrawn from the other. Continuous batching and mixing meeting the requirements of CRD-C 98 (ASTM C 685) may also be used. Delivery of concrete at the desired consistency and uniformity from batch to batch is essential to a good shotcreting operation, especially in vertical and overhead applications.

(2) Batching and mixing operations for wet-mix shotcrete are the same as batching of conventional concrete. Batch plants range from small single-scale manual plants to large automated plants. Mixing is done in transit mixers or in a central mixer at the plant. The addition of special materials such as fibers, silica fume, polymers, and others is done as would be done for conventional concrete.

e. Admixture dispensers. For either the dry-mix or wet-mix process, admixture dispensers should receive special attention to ensure that the material is dispensed within ±3 percent of the required batch quantity and is uniformly dispersed through the mixture.

6-3. Shotcrete Application Techniques

a. Techniques and procedures. The nozzling techniques and procedures used in applying shotcrete greatly affect the quality of the shotcrete and the amount and composition of rebound. Rebound material may become entrapped in succeeding shotcrete if poor nozzling techniques are followed. The entrapment of rebound results in a decrease in the ultimate strength and durability of the shotcrete.

b. Nozzle angle. Plane surfaces should generally be shotcreted with the nozzle held at 90 degrees to the surface. When this principle is not followed, excessive rebound and decreased compaction usually result. Two exceptions to this practice occur when gunning an interior corner or when encasing reinforcing steel. Interior corners should be gunned by directing the nozzle in the plane bisecting the angle of intersection of the two surfaces (Figure 6-1) which reduces the amount of rebound entrapped in the corner. Areas with reinforcing steel should be gunned at a slight angle from each side. When gunning horizontal work, the nozzle should be held at a slight angle from vertical so that rebound is blown onto completed work for ease of removal.

c. Nozzle distance. The optimum distance between the shotcrete nozzle and the surface is generally about 3 feet. Rebound increases when the nozzle is held at a distance greater than 3 feet and compaction and strength of the shotcrete are reduced. Rebound can also increase if the nozzle is held closer than 3 feet and no reduction in pressure and delivery rate is made. At reduced distances, the nozzleman is more exposed to rebounding particles.

d. Nozzle motion. A steady circular or elliptical movement of the nozzle across the surface is the proper gunning technique (Figure 6-2). The nozzle should not be directed toward one spot for extended periods since this causes increased rebound and difficulty in controlling the thickness of the layer. When the nozzle is not consistently moved, areas of well-compacted material are formed adjacent to areas that are poorly compacted.

(1) Overspray results when shotcrete material is carried by the airstream but not deposited at the point of application. The material has a reduced cement content and is not consolidated by high-velocity impact resulting in a zone of undesirable low-strength material. A sand pocket results if the overspray is encased by shotcrete. Overspray can he avoided by following proper nozzling techniques.

(2) Horizontal and vertical corners should be filled first to eliminate the common collection areas for overspray. The center of the surface being shotcreted may then be brought to the required thickness.

e. Encasing reinforcement. Encasement of reinforcing steel with shotcrete must be done carefully to prevent pockets of uncemented aggregates from forming behind the bars (Figure 6-3).

(1) To prevent formation of these sand or rock pockets, the nozzle should be held close to the reinforcing bar and at a slight angle from the perpendicular to force material around and behind the bar. The front of the bar should remain clean and free of buildup until the entire bar is encased. A blowpipe should be used during the gunning operation to remove accumulation on the front of the bars and entrapped rebound from behind the bars (Figure 6-4). The shotcrete mixture should be slightly wetter than normal, although not so wet that there will be sloughing behind the bars. Where bars are closely spaced, more than one bar may be shot from each location.

(2) Proper installation of reinforcing bars and mesh can reduce encasement problems and the potential for major sand pocket voids. All obstacles to the flow of the shotcrete material stream should be kept to a minimum size. For example, a No. 4 bar can be readily encased by a skilled nozzleman, while a No. 8 bar would be very difficult to properly encase.

f. Progression of work.

(1) The bondable material to which shotcrete is to be applied should be clean and free of bond-breaking substances such as dirt, grease, oil, curing agents, paints, or deteriorated material. Once the surface is properly cleaned and prepared for shotcrete, a shooting technique must be used which does not foul or dirty the clean surface.

(2) A thin initial coat of shotcrete should be rapidly applied to the selected work surface before starting the layering of shotcrete. This initial coat protects prepared surfaces from contamination with overspray or rebound. The work area should be of such size that the surface can be maintained "wet" with fresh shotcrete so that initial set does not occur until after shooting of the area is completed. Therefore, the work area size is dependent upon sun exposure, ambient temperature, wind velocity, admixtures in the shotcrete, accessibility of the work surface, equipment being used, and the nozzleman's ability.

(3) Once the initial bonding or wet coat is applied to the entire work area, a second pass over the area may proceed at a slower rate. This pass allows the formation of a thicker buildup of material over the first bonding layer. Corners should be filled first to prevent the accumulation of overspray and rebound, followed by application onto the flat areas.

(4) When the limited work area has been completed, rebound and overspray should be removed from adjoining areas with air before the shotcrete takes initial set. This cleaning effort may be expedited by the finisher and other laborers with trowels, shovels, brooms, and other available equipment.

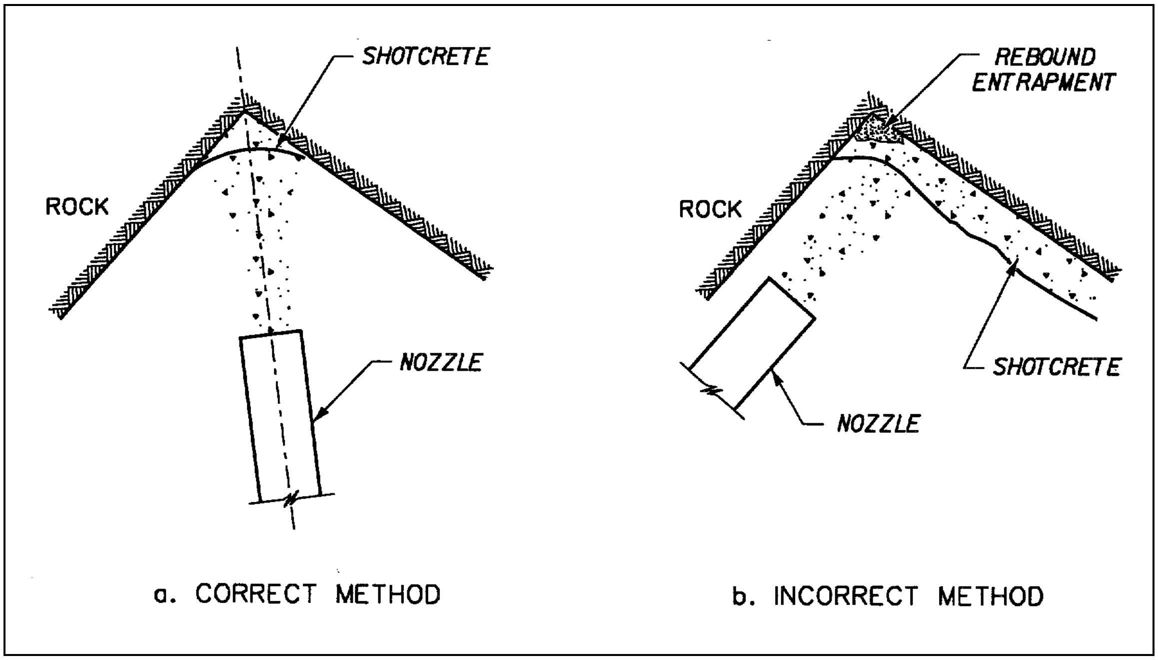

Figure 6-1. Shotcreting interior corners (Mahar, Parker, and Wuellner 1975)

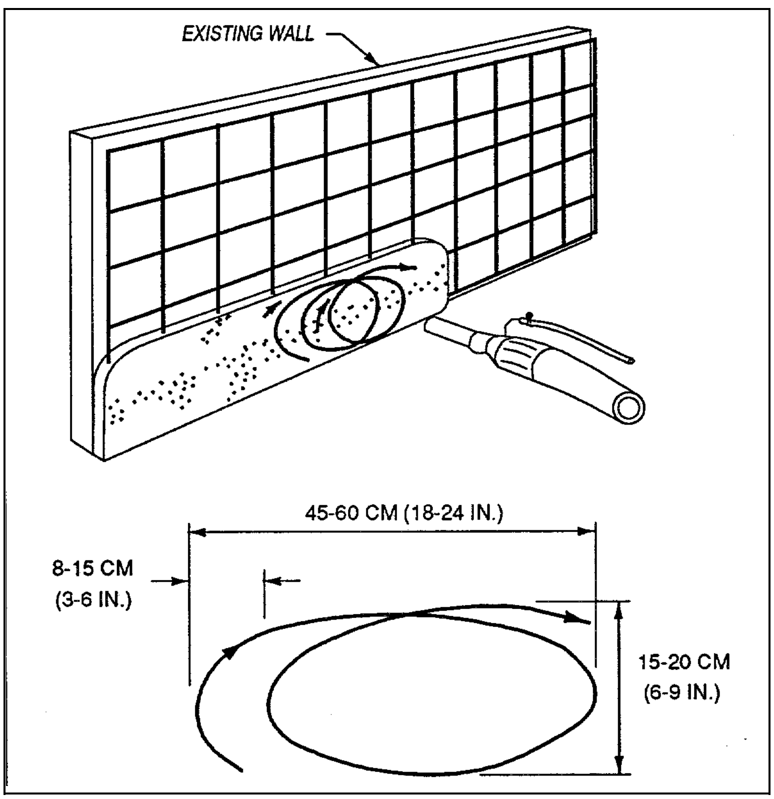

Figure 6-2. Shotcrete nozzle motion (after Ryan 1973)

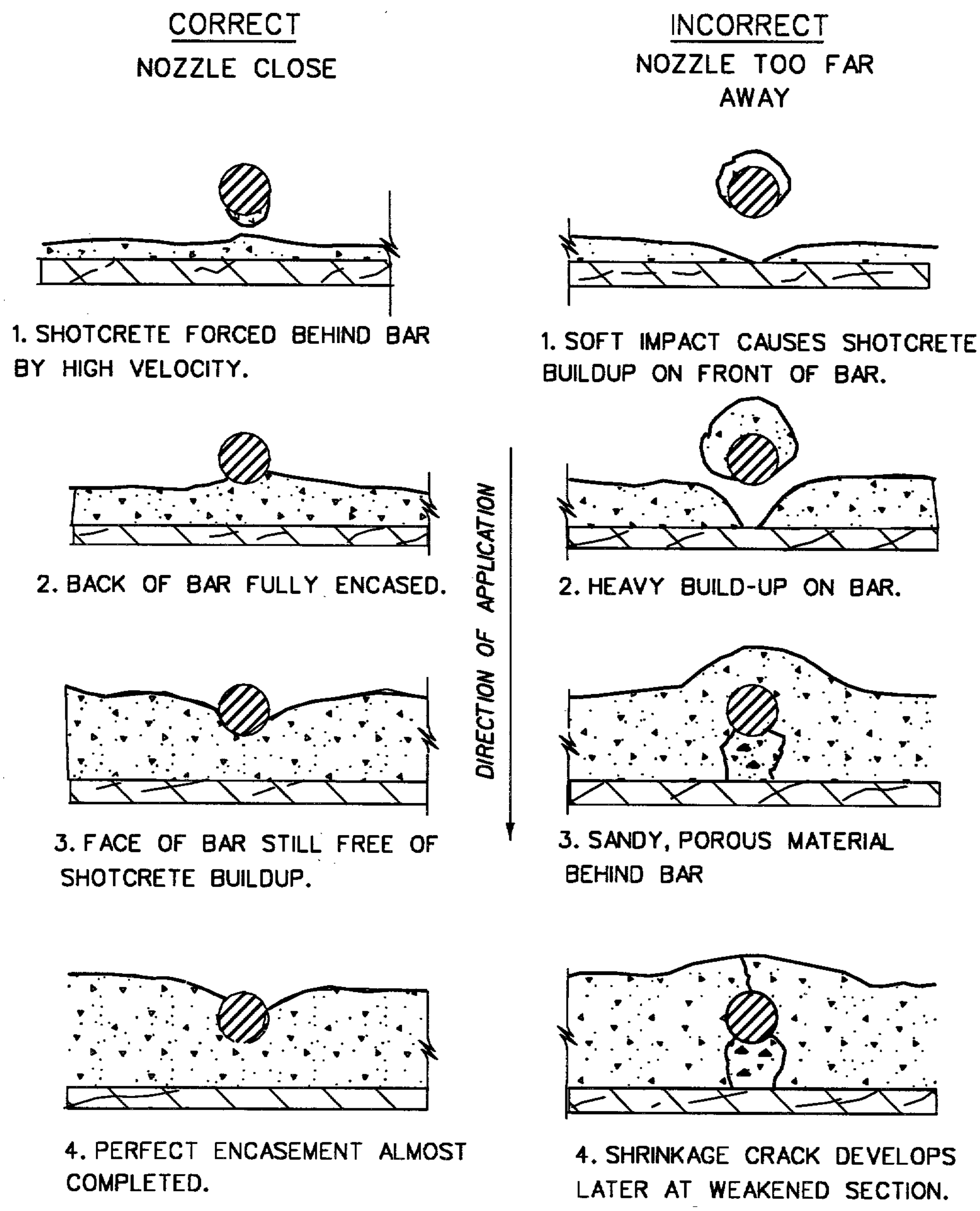

Figure 6-3. Correct and incorrect methods of encasing reinforcing bar with shotcrete (paragraph A-1, ACI 1991d; copyright permission granted by ACI)

(5) When gunning vertical work, shotcrete should be applied from the bottom up. For thick walls, "shelf" or "bench" gunning may be used, where, instead of gunning directly against the vertical surface, a thick layer of shotcrete is built up from the bottom, maintaining a 45-degree slope.

g. Protection. Shotcrete cannot normally be applied during periods of rain, snow, or high wind. Rain may wash out the cement leaving a sandy surface, or it may saturate the shotcrete and cause sloughing or sagging. Strong winds will separate the material between the nozzle and the point of deposit, reducing strength. If proper shields cannot be erected to reduce the effects of the wind, the shotcreting should be discontinued. Because shotcrete rebound, overspray, and dust can damage adjacent surfaces, protection for these surfaces may be needed. Means of protection include plastic or cloth covers, masking materials, temporary coatings, or plywood or other wood. If protection is not feasible, then adjacent surfaces should be cleaned before the contaminant hardens.

h. Construction joints. Construction joints are normally tapered about one-half of the shotcrete thickness or a maximum of 1 inch thick to an edge, over a width of 10 to 20 inches. Square joints can be cut by a trowel at initial set. Ordinarily, square joints should be avoided in shotcrete construction because they form a trap for overspray and rebound. However, if the joint will be subjected to compressive stress, square or butt joints may be required. Steps must be taken to avoid or remove trapped rebound at the joint. The entire joint should be thoroughly cleaned and wetted prior to the application of additional shotcrete.

i. Contraction joints. These joints may be required in some applications, such as canal linings, to control shrinkage cracking of the shotcrete. The joints may be created by prepositioning strips of plastic or metal, and leaving them in place, or by sawcutting the newly hardened shotcrete. Contraction joints are not generally incorporated in such work as tunnel linings or slope protection.

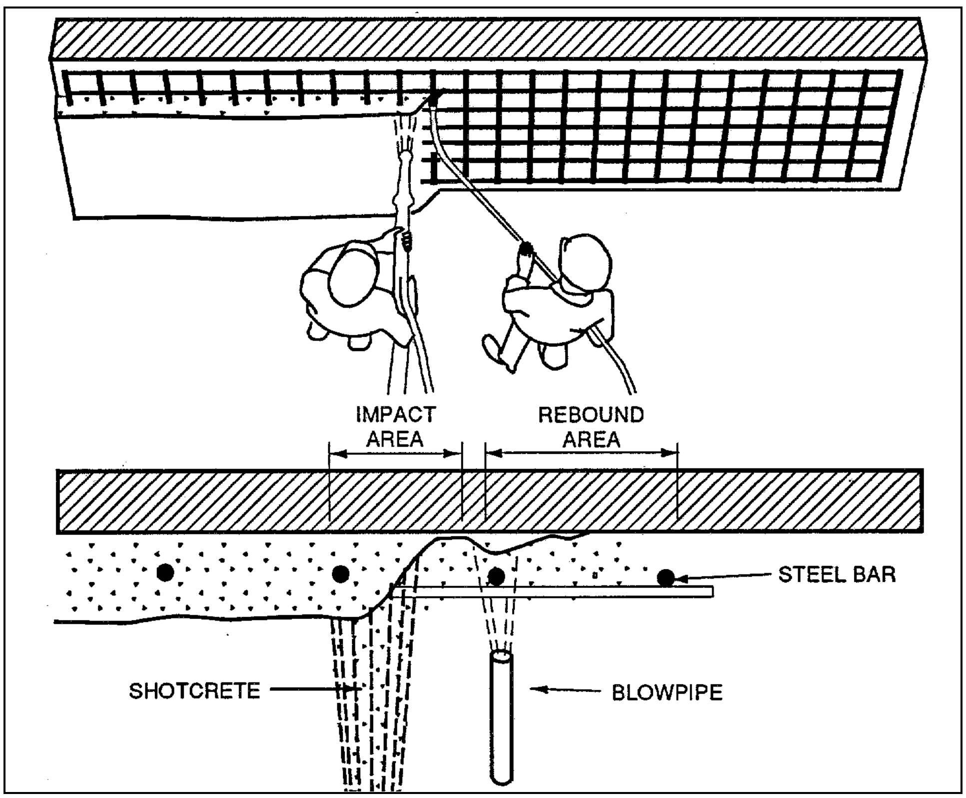

Figure 6-4. Use of a blowpipe in removing rebound for proper encasement of reinforcing bars (after Ryan 1973)

j. Waterstop. Due to the difficulty of placing shotcrete around waterstops, use of waterstops in shotcrete applications should be avoided.

k. Multiple layers. When a layer of shotcrete is to be covered by a succeeding layer, it should first be allowed to develop its initial set. Then all loose material and rebound should be removed by brooming, scraping, or other means. Surface deposits which take a final set should be removed by sandblasting and the surface cleaned with an air-water jet.

l. Time limitations. The time from the batching of shotcrete to final placement should not exceed 45 minutes during warm weather, when ambient temperatures exceed 80 °F. When ambient temperatures are below 80 °F, the time may be extended to a maximum time of 90 minutes. These requirements apply to both wet-mix and dry-mix shotcrete. These time limits may need to be shortened to accommodate additions of polymers, silica fume, or other additives.

6-4. Rebound

a. Rebound is aggregate and cement paste that bounce off the surface during the application of shotcrete because of collision with the hard surface, the reinforcement, or the aggregate particles themselves. The amount of rebound varies with the position of the work, air pressure, cement content, water content, maximum size and grading of aggregate, amount of reinforcement, and thickness of layer. The percent of rebound from conventional cement-aggregate shotcrete by three general types of work surfaces is shown in Table 6-1.

Table 6-1
Rebound from Conventional Cement-Aggregate Shotcrete

	Percent of Rebound, by Mass	
Work Surfaces	Dry-mix	Wet-mix
Floors or slabs	5-15	0-5
Sloping and vertical walls	5-25	5-10
Overhead work	25-50	10-20

b. Rebound will be less for small-aggregate mixtures and more for large-aggregate mixtures. Rebound of silica-fume shotcrete mixes may be as much as 50 percent less than other mixtures because of the highly cohesive nature of silica fume.

c. Initially, the percentage of rebound is large but becomes less after a cushion of fresh shotcrete has been built up. While rebound contains some cement paste, it consists mostly of the coarser aggregate particles. Consequently, the cement content of the in-place shotcrete is higher because of aggregate loss from rebound. This increases the strength of the shotcrete and also increases the tendency toward shrinkage and subsequent shrinkage cracking. Rebound should not be worked back into the construction by the nozzleman. If it does not fall clear of the work, it must be removed. Trapped rebound, if not removed, creates sandy, porous areas and laminations in the cross section which are a great detriment to shotcrete quality. Rebound should not be salvaged and included in later batches because of the danger of contamination. Also, the cement content, state of hydration, and the grading of the aggregate in rebound are all variable and unpredictable.

d. Measurement of rebound from test panels should be considered before beginning the shotcrete operation. Rebound can be collected in traps placed on the ground in front of the panel. The percentage of rebound is determined by dividing the mass of the rebound material by the mass of the shotcrete delivered through the nozzle and multiplied by 100.

e. Shotcrete operations pose the threat of injury from high velocity particles of rock, cement, and dust striking eyes and other exposed areas of the body. Rebounded particles constitute the same type of hazard as the materials in the shotcrete stream, but to a lesser degree since impact on the surface usually reduces their velocities. Suitable headgear must be worn in the vicinity of the nozzling operation. The nozzleman is less likely to be injured than a workman who stands close to the nozzle but at right angles to the material stream. Use of protective clothing and safety equipment will help prevent serious injury from rebound.

6-5. Finishing

a. The natural gun finish is preferred from the standpoints of both structural soundness and durability. Further finishing may disturb the section, harming the bond between the shotcrete and reinforcement or between the shotcrete and the underlying material, and creating cracks in the shotcrete. Additional finishing may also be difficult to accomplish, especially for the drier mixtures. However, the natural gun finish is unacceptable for some structures because of its roughness. Where greater smoothness or better appearance is required, special finishes, as listed, must be applied.

b. After the surface has taken its initial set (crumbling slightly when cut), excess material outside the forms and ground wires may be sliced off using a sharp-edged cutting screed. Upward cutting motions have a tendency to pull the material apart. The ground wires should then be removed, and the irregularities floated. The finish may be left in this condition, or it may be broomed.

c. If a still finer finish or better appearance is desired, a flash coat may be used. This is a thin surface coating containing finer sand than normal and laid on with an application nozzle held well back from the work. It should be applied to the shotcrete surface as soon as possible after the screeding.

d. If desired, the as-gunned finish or flash coat may be followed by surface finishing using one or more of the following tools:

(1) Wood float, giving a granular texture.

(2) Rubber float, giving a coarse texture and finish.

(3) Steel trowel, giving a very smooth finish.

6-6. Curing and Protection

a. Proper curing of shotcrete is extremely important to ensure proper hydration, matrix and bond strength development, and to prevent cracking due to drying shrinkage. Note that the rate of bond strength development is significantly slower than compressive or tensile strength development. The curing procedures of ACI Standard 308 (paragraph A-1, ACI (1991c)) should be followed. The thin sections commonly used in shotcrete construction are particularly susceptible to drying shrinkage. Surfaces should be kept continuously moist for at least 7 days. After this time interval, the shotcrete has gained sufficient tensile strength to resist shrinkage strains, and the permeability near its exposed surface is low enough to minimize loss of water from the interior of the section. Membrane curing is permissible only when drying conditions are not severe, where no additional shotcrete or paint is to be applied, and where it is esthetically acceptable. Coverage rates of rough shotcrete surfaces should be twice what is used on conventional concrete surfaces.

b. Silica-fume shotcrete must always be continuously moist cured to assure proper strength gain and surface durability. It is common to specify the use of fog nozzles to maintain a moist condition on all new surfaces. While less convenient, sprinklers and soaker hoses can provide adequate curing so long as it can be assured that all the surface area is maintained in a moist condition.

6-7. Repair of Surface Defects in New Shotcrete

a. Surface defects must be repaired as soon as possible after initial placement of the shotcrete. All shotcrete which lacks uniformity, which exhibits segregation, honeycombing, or lamination, or which contains any dry patches, slugs, voids, or sand pockets must be removed and replaced with fresh shotcrete.

b. Core holes are not to be repaired with shotcrete. Instead, they should be filled with a dry-pack mortar.

c. Where surface crazing, shrinkage cracks, or low strengths occur, additional analysis is required to determine the effect upon the structure. In some cases, no remedial action may be required; in others a surface treatment with a polymer may be satisfactory. In cases where the performance of the structure is significantly degraded, the affected shotcrete areas must be removed and replaced with sound shotcrete.